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Short communication

Natural resistance of exotic wood species to the Formosan subterranean termite (Isoptera: Rhinotermitidae)

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ABSTRACT

The purpose of this study was to evaluate survival and wood consumption of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, on ten different species of wood used as commercial lumber. Six of the wood species had natural resistance to termites and caused an average of >75% mortality. Southern yellow pine and spruce were the most palatable and teak was the most resistant of the wood tested. A test was also conducted to compare survival of termites on resistant wood with survival under starvation conditions after three and six weeks. After six weeks, survival of termites on teak was significantly lower than in the starvation control, suggesting that at least some of the termite mortality on teak may have been due to toxicity. Toxic chemical components of teak hold the most promise as wood preservatives.

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Introduction

Subterranean termites are major structural pests. The global economic impact of termite pests is estimated to be at least $40 billion (Rust and Su, 2012). The Formosan subterranean termite, *Coptotermes formosanus* Shiraki is one of the most economically important termite pests. Wood preservatives have been commonly used to control termite pests. Chromated copper arsenate (CCA) had been widely used to prevent termite damage since the 1930's. However, due to environmental concerns, residential use of CCA has recently been banned or restricted in many countries (Roszaini et al., 2013). Concerns about environmental contamination by wood preservatives have increased interest in compounds in naturally resistant wood that have antifeedant and toxic effects on termite pests.

Numerous studies have documented the natural resistance of certain wood species to termite attack (Smythe and Carter, 1969, 1970a,b; Bultman et al., 1979; Su and Tamashiro, 1986; Grace and Yamamoto, 1994; Delate and Grace, 1995; Escoubas et al., 1995; Morales-Ramos and Rojas, 2001; Grace and Tome, 2005; Arango et al., 2006). The heartwood of many wood species contains allelochemicals that act as antifeedants and toxicants (Scheffrahn, 1991). Extracts and natural products derived from wood have been shown to have antitermitic properties (Carter et al., 1978; Carter and Beal, 1982; Carter and de Camargo, 1983; Scheffrahn et al., 1988; Kawaguchi et al., 1989; Reyes-Chilpa et al., 1995; Ohmura et al., 2000; Chang et al., 2001; Blaske et al., 2003; Kartal and Green, 2003; Chen et al., 2004; Ganapaty et al., 2004; Watanabe et al., 2005; Morimoto et al., 2006; Cheng et al., 2007; Hwang et al., 2007; Mao and Henderson, 2007; Santana et al., 2010; Roszaini et al., 2013).

The purpose of this study was to examine the survival and wood consumption of Formosan subterranean termites on commercial lumber from ten different wood species. The most and least palatable wood species were identified in no-choice tests. We also compared survival of termites feeding on resistant wood with termites kept under starvation conditions to determine whether or not the toxicity of the wood would cause greater mortality than starvation alone.

Materials and methods

Termite collections and maintenance

Termites were collected from field colonies in City Park, New Orleans, LA, using cylindrical irrigation valve boxes (lid: 17.8 cm

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diam; base: 21.6 cm; height: 22.9 cm) (NDS, Inc, Lindsay, CA) that are buried in the ground and filled with 100–150 blocks (7.5 by 3.8 by 0.8 cm) of wood (spruce, *Picea* sp.). Termites of at least the 3rd instar were used in experiments within two months of field collection. Termites were kept in the lab in 5.6-L covered plastic boxes containing moist sand and blocks of spruce *Picea* sp. until they were used in experiments.

Wood species

Ten different wood species used as commercial lumber were used in tests: spruce, *Picea* sp., southern yellow pine, *Pinus* sp., yellow birch, *Betula alleghaniensis* Britton, northern red oak, *Quercus rubra* L., redwood, *Sequoia sempervirens* (D. Don), Alaska yellow cedar, *Chamaecyparis nootkatensis* D. Don, Peruvian walnut, *Juglans boliviana* (C. DC), jatoba, *Hymenaea courbaril* L., Honduras mahogany, *Swietenia macrophylla* King, and teak, *Tectona grandis* L. Commercial lumber labeled as spruce or southern yellow pine are actually a mixture of several species within the genera *Picea* and *Pinus*, respectively. All wood was purchased at Riverside Lumber in New Orleans, LA, except for the spruce which was purchased at Dash Lumber in New Orleans, LA.

Termite assays

No-choice tests were conducted using polystyrene, cylindrical screwtop containers (9 cm high by 7 cm diam.) (Consolidated Plastics, Twinsburg, Ohio) filled with 50 g of sand (Play Sand, Quikrete, Atlanta GA) and moistened with 10 ml of distilled water. Wood blocks (4.2 cm × 3.8 cm × 1 cm) of each wood species were oven-dried at 90 °C for 24 h, weighed, labeled, and numbered before the experiment. At the end of each assay, blocks were cleaned, oven-dried, and re-weighed. Wood consumption was determined by calculating the weight loss of each block. Termites were collected from five different colonies (Colonies 1–5). There were 200 termites per replicate (190 workers: 10 soldiers). Containers were kept in a dark environmental chamber at 28 °C, 97% RH.

Experiment 1

A test was conducted to determine the relative palatability of the 10 species of commercial lumber. There were five replicates of each wood species, with one replicate of each colony for each wood species. After six weeks, termite survival and wood consumption were determined.

Experiment 2

A test was conducted to compare survival of termites on resistant wood with survival under starvation conditions after three and six weeks. Treatments included the following: no food, birch, redwood, and teak. The palatable wood, birch, was selected to serve as a measure of termite vitality during the three and six week periods. Redwood and teak were selected because both species showed natural resistance to termites in Experiment 1, but there was significantly greater consumption of redwood than teak. There were five replicates of each wood species at each time period, with one replicate of each colony for each species at each time period.

Statistical analysis

Differences in survival and wood consumption were compared using a Kruskal–Wallis one-way ANOVA and means were separated using a Student–Newman–Keuls test with ranked sums. For Experiment 2, survival in treatments with no food, birch, redwood, or teak and wood consumption on birch, redwood, or teak were compared in both a 3-week and a 6-week test. All analyses were conducted using SigmaPlot 11.0 (Systat Software, 2008).

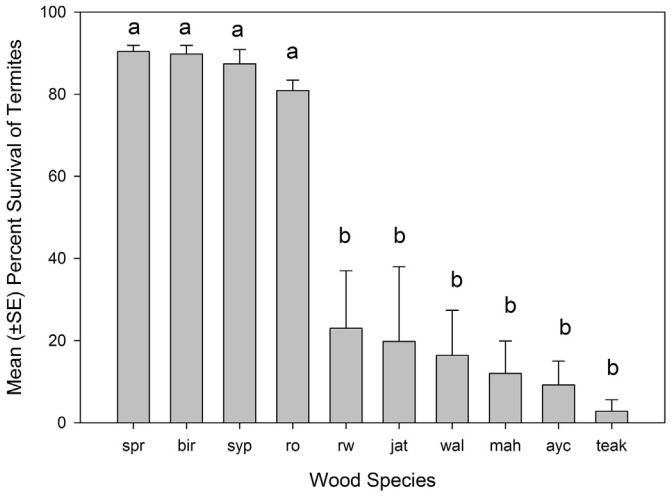

Fig. 1. Mean (±SE) percent survival of termites in six week no-choice tests evaluating ten species of wood: spr = spruce, bir = birch, syp = southern yellow pine, ro = red oak, rw = redwood, jat = Brazilian jatoba, wal = Peruvian walnut, mah = Honduran mahogany, ayc = Alaska yellow cedar. Bars followed by the same letter are not significantly different (Student–Newman–Keuls test: P > 0.05).

Results

Experiment 1

There were significant differences in survival of termites ($H = 35.2$; df = 9, 49: $P < 0.001$) and wood consumption ($H = 40.0$; df = 9, 49; $P = <0.001$) on different wood species. Termite survival was significantly greater on birch, southern yellow pine, spruce, and red oak than on the other wood species (Fig. 1). The six wood species with natural resistance to Formosan subterranean termites caused an average of >75% mortality.

Consumption was significantly greater on spruce and southern yellow pine than all the other wood species. Consumption of birch

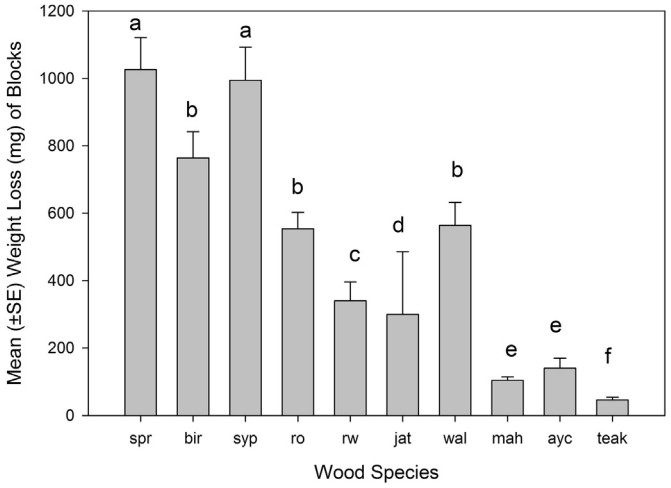

Fig. 2. Mean (±SE) weight loss (mg) of blocks in six week no-choice tests evaluating ten species of wood: spr = spruce, bir = birch, syp = southern yellow pine, ro = red oak, rw = redwood, jat = Brazilian jatoba, wal = Peruvian walnut, mah = Honduran mahogany, ayc = Alaska yellow cedar. Bars followed by the same letter are not significantly different (Student–Newman–Keuls test: P > 0.05).

Table 1
Mean (±SE) percent survival of Formosan subterranean termites, mean (±SE) weight loss (mg), and mean (±SE) percent weight loss of wood in a no-choice test after three and six weeks.

No-choice test	Mean (±SE) percent termite survival	Mean (±SE) weight loss of wood (mg)	Mean (±SE) percent weight loss of wood
3 Week test			
Starvation Control	76.3 ± 2.9b	–	–
Birch	88.2 ± 1.7a	682.0 ± 144.8a	7.9 ± 1.6a
Redwood	80.1 ± 1.4b	538.0 ± 84.3a	8.9 ± 1.5a
Teak	73.3 ± 3.6b	68.0 ± 8.0b	1.1 ± 0.1b
6 Week test			
Starvation Control	28.3 ± 11.3b	–	–
Birch	88.6 ± 2.7a	1180.0 ± 143.4a	13.7 ± 1.5a
Redwood	47.6 ± 9.4b	530.0 ± 49.2b	8.7 ± 0.8b
Teak	7.6 ± 6.9c	108.0 ± 9.7c	1.8 ± 0.2c

Means within each test followed by the same letter are not significantly different ($P \geq 0.05$) using Student–Newman–Keuls test for ranked sums.

was not significantly different than consumption of red oak and Peruvian walnut. Of the naturally resistant wood species, redwood was the most palatable and teak was the least. Brazilian jatoba was more palatable than mahogany and Alaska yellow cedar (Fig. 2). Termites caused very little feeding damage on Alaska yellow cedar, mahogany, and teak.

In the no-choice test comparing ten wood species, average survival on Peruvian walnut was only 16.4% after six weeks, but the amount of Peruvian walnut consumed was similar to the amount of birch and red oak consumed. Although Peruvian walnut caused high mortality, feeding damage was relatively high compared with the very low rates of feeding damage on Alaska yellow cedar, mahogany and teak.

Experiment 2

There were significant differences in termite survival after three weeks ($H = 11.5$; $df = 3$; $P = 0.009$) and six weeks ($H = 14.3$; $df = 3$; $P = 0.003$). After three and six weeks, survival of termites was significantly greater on birch than on the other three treatments. After six weeks, survival of termites on teak was significantly lower than in the starvation control. However, there was no difference in the survival of termites on the redwood blocks compared with the starvation control after six weeks. Wood consumption differed significantly after three ($H = 9.8$; $df = 2$, $P = 0.007$) and six weeks ($H = 12.5$; $df = 2$, $P = 0.002$). Consumption on teak was significantly lower than consumption on birch and redwood after three and six weeks. Consumption on redwood was significantly lower than consumption on birch after six week (Table 1).

Discussion

Southern yellow pine and spruce were the most palatable and teak was the most resistant of the wood species tested. The natural resistance of redwood, Alaska yellow cedar, mahogany, and teak to subterranean termites has been previously documented in other studies (Grace and Yamamoto, 1994; Morales-Ramos and Rojas, 2001; Ngee et al., 2004; Arango et al., 2006). Although studies examining termite feeding on the Brazilian jatoba, *Hymenaea courbaril* L were not found, heartwood and alkaloidal extracts from a related Brazilian jatoba species, *Hymenaea stigonocarpa* displayed antitermitic activity to the termite, *Nasutitermes corniger* Motschulsky (Santana et al., 2010). Brazilian jatoba was more resistant than redwood and less resistant than Alaska yellow cedar, mahogany, and teak.

This study is the first report of termite feeding and survival on Peruvian walnut, *Juglans boliviana*. Although survival of termites on Peruvian walnut was low, termites caused significant feeding damage to the wood. Therefore, the natural resistance of Peruvian walnut may not provide adequate protection of the wood from degradation caused by termites.

In both experiments, termite survival was the lowest on teak. When survival of termites kept under starvation conditions for six weeks was compared with survival on teak, termite survival on teak was significantly lower, indicating that at least some of the mortality may have been due to toxic compounds in teak. Teak contains quinones that act as antitermitic agents (Lukmandaru and Takahashi, 2008, 2009). Because of the high levels of natural resistance of teak to Formosan subterranean termites, chemical constituents of teak heartwood appear to hold the most promise as new wood preservatives that could be effective against a major economic pest of wood products.

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References

Arango, R., Green III, A.F., Hintz, K., Lebow, P.K., Miller, R.B., 2006. Natural durability of tropical and native woods against termite damage by *Reticulitermes flavipes* (Kollar). Int. Biodeterior. Biodegrad. 57, 146–150.
Blaske, V.-U., Hertel, H., Forschler, B.T., 2003. Repellent effects of isoborneol on subterranean termites (Isoptera: Rhinotermitidae) in soils of different composition. J. Econ. Entomol. 96, 1267–1274.
Bultman, J.D., Beal, R.H., Ampong, F.F.K., 1979. Natural resistance of some tropical African woods in *Coptotermes formosanus* Shiraki. For. Prod. J. 29, 46–51.
Carter, F.L., Beal, R.H., 1982. Termite responses to susceptible pine wood treated with antitermitic wood extracts. Int. J. Wood Preserv. 2, 185–191.
Carter, F.L., de Camargo, C.R.R., 1983. Testing antitermitic properties of Brazilian woods and their extracts. Wood Fiber Sci. 15, 350–357.
Carter, F.L., Farlo, A.M., Stanley, J.B., 1978. Termiticidal components of wood extracts: 7-methyljuglone from *Diospyros virginiana*. J. Agric. Food Chem. 26, 869–873.
Chang, S.T., Cheng, S.S., Wang, S.Y., 2001. Antitermitic activity of essential oils and components from Taiwania (*Taiwania cryptomerioides*). J. Chem. Ecol. 27, 717–724.
Chen, K., Ohmura, W., Doi, S., Aoyama, M., 2004. Termite feeding deterrent from Japanese larch wood. Bioresour. Technol. 95, 129–134.
Cheng, S.S., Chang, H.T., Wu, C.-L., Chang, S.T., 2007. Anti-termitic activities of essential oils from coniferous trees against *Coptotermes formosanus*. Bioresour. Technol. 98, 456–459.
Delate, K.M., Grace, J.K., 1995. Susceptibility of neem to attack by the Formosan subterranean termite, *Coptotermes formosanus* Shir. (Isopt., Rhinotermitidae). J. Appl. Entomol. 119, 93–95.
Escoubas, P., Lajide, L., Mizutani, J., 1995. Termite antifeedant activity in *Afromomum melegueta*. Phytochemistry 40, 1097–1099.
Ganapaty, S., Thomas, P.S., Fotso, S., Laatsch, H., 2004. Antitermitic quinones from *Diospyros sylvatica*. Phytochemistry 65, 1265–1271.
Grace, J.K., Yamamoto, R.T., 1994. Natural resistance of Alaskan-cedar, redwood, and teak to Formosan subterranean termites. For. Prod. J. 44, 41–45.
Grace, J.K., Tome, C.H.M., 2005. Resistance of the Indonesian woods bangkirai (*Shorea laevis*) and Merbau (*Intsia palembanica*) to Formosan subterranean termite attack. Sociobiology 45, 503–509.

Hwang, W.J., Kartal, S.N., Yoshimura, T., Imamura, Y., 2007. Synergistic effect of heartwood extractives and quaternary ammonium compounds on termite resistance of treated wood. J. Pest Manag. Sci. 63, 90–95.
Kartal, S.N., Green III, F., 2003. Decay and termite resistance of medium density fiberboard (MDF) made from different wood species. Int. Biodeterior. Biodegrad. 51, 29–35.
Kawaguchi, H., Kim, M., Ishida, M., Ahn, Y.-J., Yamamoto, T., Yamaoka, R., Kozuka, M., Goto, K., Takhashi, R., 1989. Several antifeedants from *Phellodendron amurense* against *Reticulitermes speratus*. Agric. Biol. Chem. 53, 2635–2640.
Lukmandaru, G., Takahashi, K., 2008. Variation in the natural termite resistance of teak (*Tectona grandis* Linn fil.) wood as a function of tree age. Ann. For. Sci. 65, 708.
Lukmandaru, G., Takahashi, K., 2009. Radial distribution of quinones in plantation teak (*Tectona grandis* L.f.). Ann. For. Sci. 66, 605.
Mao, L., Henderson, G., 2007. Antifeedant activity and acute and residual toxicity of alkaloids from *Sophora flavescens* (Leguminosae) against Formosan subterranean termites (Isoptera: Rhinotermitidae). J. Econ. Entomol. 100, 866–870.
Morales-Ramos, J.A., Rojas, M.G., 2001. Nutritional ecology of the Formosan subterranean termite (Isoptera: Rhinotermitidae): feeding response to commercial wood species. J. Econ. Entomol. 94, 516–523.
Morimoto, M., Fukumoto, H., Hiratani, M., Chavasiri, W., Komai, K., 2006. Insect antifeedants, pterocarpol, in heartwood of *Pterocarpus macrocarpus* Kruz. Biosci. Biotechnol. Biochem. 70, 1864–1868.
Ngee, P.-S., Tashiro, A., Yoshimura, T., Jaal, Z., Lee, C.-Y., 2004. Wood preference of selected Malaysian subterranean termites (Isoptera: Rhinotermitidae, Termitidae). Sociobiology 43, 535–550.
Ohmura, W., Doi, S., Aoyama, M., 2000. Antifeedant activity of flavonoids and related compounds against the subterranean termite *Coptotermes formosanus* Shiraki. J. Wood Sci. 46, 149–153.
Reyes-Chilpa, R., Viveros-Rodríguez, N., Gomez-Garibay, F., Alvarez-Solano, D., 1995. Antitermitic activity of *Lonchocarpus castilloi* flavonoids and heartwood extracts. J. Chem. Ecol. 21, 455–463.
Rust, M.K., Su, N.-Y., 2012. Managing insects of social importance. Ann. Rev. Entomol. 57, 355–375.
Roszaini, K., Nor Azah, M.A., Mailina, J., Zaini, S., Faridz, Z.M., 2013. Toxicity and antitermite activity of the essential oils from *Cinnamomum camphora, Cymbopogon nardus, Melaleuca cajuputi* and *Dipterocarpus* sp. against *Coptotermes curvignathus*. Wood Sci. Technol. 47, 1273–1284.
Santana, A.L.B.D., Maranhão, C.A., Santos, J.C., Cunha, F.M., Conceicão, G.M., Bieber, L.W., Nascimento, M.S., 2010. Antitermitic activity of extractives from three Brazilian hardwoods against *Nasutitermes corniger*. Int. Biodeterior. Biodegrad. 64, 7–12.
Scheffrahn, R.H., 1991. Allelochemical resistance of wood to termites. Sociobiology 19, 257–282.
Scheffrahn, R.H., Hsu, R.-C., Su, N.-Y., Huffmann, J.B., Midland, S.L., Sims, J.J., 1988. Allelochemical resistance of bald cypress, *Taxodium distichum*, heartwood to the subterranean termite, *Coptotermes formosanus*. J. Chem. Ecol. 14, 765–776.
Smythe, R.V., Carter, F.L., 1969. Feeding responses to sound wood by the eastern subterranean termite, *Reticulitermes flavipes*. Ann. Entomol. Soc. Am. 62, 335–337.
Smythe, R.V., Carter, F.L., 1970a. Feeding responses to sound wood by *Coptotermes formosanus*, *Reticulitermes flavipes*, and *R. virginicus* (Isoptera: Rhinotermitidae). Ann. Entomol. Soc. Am. 63, 841–847.
Smythe, R.V., Carter, F.L., 1970b. Survival and behavior of three subterranean termite species in sawdust of eleven wood species. Ann. Entomol. Soc. Am. 63, 847–850.
Su, N.Y., Tamashiro, M., 1986. Wood-consumption rate and survival of the Formosan subterranean termite (Isoptera: Rhinotermitidae) when fed on six woods used commercially in Hawaii. Proc. Hawaii. Entomol. Soc. 26, 109–113.
Systat Software, 2008. SigmaPlot Statistics User's Guide, Version 11.0 ed. Systat Software, Inc., San Jose, CA.
Watanabe, Y., Mihara, R., Mitsunaga, T., Yoshimura, T., 2005. Termite repellent sesquiterpenoids from *Callitris glaucophylla* heartwood. J. Wood Sci. 51, 514–519.